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Using Advanced EDA Models for Simulation of Circuits and Systems

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Computer simulation of RF, microwave and optical circuits and systems is only as good as the models that define components, interconnections, propagation, modulation and system impairments

Electronic design automation (EDA) tools have become indispensible for designers of all electronic products. The increased complexity of circuits and systems, combined with business demands for short development times, requires the power of a computer to bring an engineer's creative idea to fruition.

Since the first calculations were programmed into early computers, the main issue has been the ability of the mathematical representation to replicate reality. Despite truly astonishing progress in model development, this issue is still paramount—the ability to create better models and algorithms never seems to catch up with the accuracy demands of new applications.

A Little History

Since this is our tutorial column for this issue, it is useful to review the development of mathematical analysis and modeling of RF, microwave and other high-speed/high-frequency circuits and systems.

Modeling began with AC circuit theory, the familiar equations that describe the behavior of passive components: ideal inductors, capacitors and resistors. Ideal amplifiers (operational amplifiers) and diodes allowed simple active circuits to be added to the calculations. Even today, this collection of ideal circuit models provides a surprisingly good starting point for low-frequency design. Of course, this is not the case at higher frequencies of operation—the basis of classic RF/microwave design.

All real-world circuits exhibit frequency-dependent behavior. The ideal components mentioned above have first-order terms (the familiar 2p*f*) for frequency but do not include additional factors that come into play at higher frequencies. The old saying is true: at high frequency, all components are simultaneously resistors, capacitors and inductors (and antennas), and all wires are transmission lines.

Today's advanced models are the result of greater precision in the representation of these high-frequency effects.

Demand Factors

The demand for improved models has been driven by several factors:

- Circuits operating at higher frequencies, as well as broader bandwidths.
- Dramatic increases in available computing power—early computers could not handle a complex model, but that has changed.
- More complex communication systems that require automated design processes to manage their development.
- Marketplace and management demands for faster product development, which also needs automated design to keep pace.
- Functional design is often combined with manufacturing design for monolithic ICs and various modular technologies like multi-chip modules (MCMs), system-on-chip (SoC) and low-temperature co-fired ceramic (LTCC) fabrication. These all require a high degree of process automation.
- Finally, growth in wireless and high-speed digital systems has required increased productivity from engineers in those specialty areas.

Now that we have established the general scope of EDA models and the factors driving their development, let's examine some of the specific characteristics of component models:

Parasitics—All advanced models include greater detail in the inclusion of parasitic capacitance and inductance. Where earlier models lumped several parasitic mechanisms into a single element of an equivalent circuit, an advanced model represents each physical source of parasitic reactance separately, a more complex, but more accurate, representation.

Frequency-dependence—Describing this area of modeling could fill books! Some of the frequency-dependent characteristics that are included in modeling include measurement-based data derived from wafer probing or de-embedded test fixtures. When possible, electromagnetic (EM) simulation is used to analyze the physical construction of components and create a behavioral model that can be used like an analytical model.

Real-world assembly—Because components are ultimately assembled onto a substrate (board, module or semiconductor), the interconnections between the components and the larger assembly must be included in the model. The models can be developed from measurements or through EM simulation. In either case, the modeled characteristics must accurately represent the specified construction, including such things as pad size, process-specific dielectric and metallization parameters, and even the nature of other components and objects in proximity.

Brand-specific models—This area of advanced modeling is experiencing a resurgence of interest as previously-developed models for a company's product line are proven to be insufficient for today's EDA environment. New model families are regularly announced by active and passive component suppliers.

System-Level Models

Every electronic product performs a function, and those functions are part of the overall design and simulation process. In the case of a wireless communication system, there are several types of models that must be accurately represented in the simulation of the entire signal path. These include:

Noise—Signal-to-noise ratio determines the reliability of all communications systems. System simulations must include accurate modeling of the noise added by both active and passive components, including both amplitude and spectral characteristics.

Time-domain behavior—Complex modulation can be degraded by time-domain variations, including excessive group delay and reflections. Models of subsystems (e.g., filters) can be developed from circuit simulation or measurements, as appropriate. Some of these are manufactured components such as SAW filters and integrated multi-function modules, and their manufacturers must be able to provide accurate behavioral models that permit accurate system-level simulation.

Non-linear models—Distortion caused by non-linear behavior is often poorly modeled, resulting in unexpectedly poor performance when a circuit is constructed and tested. A "perfect" non-linear model would include both DC and dynamic behavior—and not just in the main signal path. The response to signals impinging on the output of the device should be part of the model, to allow simulaltion of interference from external sources such as co-located transmitters! Non-linear performance of passive components is a growing area of interest, and no longer limited to the high-power portions of the system.

Electromagnetic Modeling

Electromagnetic modeling remains an extremely active area in university research, as well as practical engineering. It may be the one area of simulation that has benefitted the most from the availability of cheap computing power, because of the total number of individual computations needed for finite element or finite time difference calculations.

Because EM simulation uses a physical representation of a structure, its results can be correlated to the real world more easily than an equivalent circuit mathematical model. But solving the various derivations of Maxwell's equations is a big job, which is the price of greater simulation accuracy.

EM simulation is good enough, in some cases, to replace measured data in the development of lumped element equivalent circuit models, at least over a selected range of frequencies. Also, the size of EM problems that can be handled has grown—with enough computing power, a completed circuit board can now be modeled to evaluate its radiated emission performance and its susceptibility to incident fields.

Propagation Modeling

Although generally considered to be a separate problem than circuit/system simulation, it is appropriate to note the evolution of propagation models from statistically-based models to more accurate methods. New propagation models, while not yet perfect, include improved techniques for ray-tracing, dispersion and reflection, in environments that have multiple objects with different conductive or dielectric properties.

For anything but free-space (or nearly so) communications, the best propagation models are still measurement-based, using *in situ* test transmitters and receivers to evaluate specific sites and environments. These "good approximations" are valuable, although the randomness and complexity of the real world probably precludes a more precise simulation.